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13. ABSTRACT *(Maximum 200 words)*

The overall objective of this experimental program is to control the light emission properties and energy transfer mechanisms in nanoscale semiconductor structures in order to realize new or improved photonic devices. For nanostructures that are defined by buried heterojunction interfaces the focus is to define the regimes in which scattering and carrier collection dominate the performance of quantum well and superlattice devices. For nanostructures with exposed surfaces the focus is to understand the fundamental light emission mechanisms. The proposed research impacts device development and system architectures by demonstrating light emitters for wavelength division multiplexing, three dimensional IOEC structures, broadly tunable lasers, and low loss waveguides. Most recently the impact of these phenomena have been studied in the wide bandgap AlGaN material system. We have demonstrated stimulated emission in GaN, InGaN thin films and quantum well heterostructures. We have also done absorption measurements and observed multiple excitons.

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FINAL PROGRESS REPORT

Dr. Robert M. Kolbas

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1. "Monolithically Integrated SQW Laser and HBT Laser Driver Via Selective OMVPE Regrowth," D. B. Slater, Jr., P. M. Enquist, J. A. Hutchby, F. E. Reed, A. S. Morris, R. M. Kolbas, R. J. Trew, A. S. Lujan and J. W. Swart, Photonics Technology Letters 5, No. 7, pp. 791-794 (7 July 1993).

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22. "Absorption Coefficient, Energy Gap, Exciton Binding Energy and Recombination Lifetime of GaN Obtained from Transition Measurements," J, F. Muth, J. H. Lee, I. K. Shmagin, R. M. Kolbas, H. C. Casey, Jr., B. P. Keller, U. K. Mishra and S. P. DenBaars, to be published in Applied Physics Letters.

23. "Optical Data Storage in InGaN/GaN Heterostructures," I. K Shmagin, J. F. Muth, R. M. Kolbas, R. D. Dupuis, P. A. Grudowski, C. J. Eiting, J. Park, B. S. Shelton and D. J. H. Lambert, to be published in Applied Physics Letters.

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Conference Presentations

1. "Investigation of High Quality P-Type GaN and InGaN from Multi-Wafer-Rotating-Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, C. S. Chern, W. Kroll, R. A. Stall, C.-Y. Hwang, M. Schurman, Y. Li, W. E. Mayo, Y. Yu, S. Krishnankutty, R. M. Kolbas and S. J. Pearton, presented at the Spring Meeting of the 1995 Materials Research Society, San Francisco, California.

2. "The Role of Buffer Layers in the Deposition of Extremely High Quality Single Crystal GaN over Sapphire Substrates, " J. N. Kuznia, M. A. Khan, D. T. Olson, J. M. Van Hove, S. Krishnankutty, and R. M. Kolbas, Electronic Materials Conference, Boston, Massachusetts (1992).

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5. "Photoluminescence Characteristics of GaN-InGaN-GaN Quantum Wells," I. K. Shmagin, J. Muth, R. M. Kolbas, S. Krishnankutty, S. Keller, B. Keller, U. K. Mishra and S. DenBaars, 38th Electronic Materials Conference, Santa Barbara, CA, June 26-28, 1996.

6. "Growth of Bulk InGaN Films and Quantum Wells by Atmospheric Pressure Metalorganic Chemical Vapor Deposition,", S. Keller, B. Keller, U. K. Mishra, S. DenBaars, I. K. Shmagin, R. M. Kolbas and S. Krishnankutty, to be presented at the MOCVD Conference in Cardiff, Wales, UK, June 1996, and manuscript submitted to the MOCVD Conference Proceedings, 1996.

7. "High Quality P-type GaN and InGaN Epitaxial Growth on c-Sapphire Substrates in a Production Scale Multi-Wafer-Rotating Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, W. Kroll, R. A. Stall, M. Schurman, C. Y. Hwang, Y. Li, Y. Lu, W. E. Mayo, S. Krishnankutty, R. M. Kolbas and S. J. Pearton, Invited talk at the meeting of the ElectroChemical Society, Chicago (Oct. 1995)

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9. "Investigation of the Optical Properties of InGaN/AlGaN QW Structures Emitting in the Blue and Green Spectrum," V. A. Joshkin, M. A. Aumer, J. C. Roberts, F. G. McIntosh, S. M. Bedair, S. Krishnankutty, I. K. Shmagin, R. M. Kolbas, S. Lin and L. Wang, Materials Research Society Fall Meeting, Boston, MA, December 2-7 (1996).

10. "Determination of Refractive Index and Absorption Coefficient of Gallium Nitride from Optical Transmission, Reflectance and Photoluminescence", J. F. Muth, I. K. Shmagin, R. M. Kolbas, S. Krishnankutty, S. Keller, U. K. Mishra, and S. P. DenBaars, Materials Research Society Fall Meeting, Boston, MA, December 2-7 (1996).

11. "Growth of Bulk AlN and GaN Single Crystals by Sublimation", C. M. Balkas, Z. Sitar, T. Zheleva, L. Bergman, I. K. Shmagin, J. F. Muth, R. M. Kolbas, R. Nemanich, and R. F. Davis, Materials Research Society Meeting, Boston, MA, Dec. 2-7, 1996.

12. "Absorption Coefficient, Exciton Binding Energy and Bandgap of GaN," J. F. Muth, I. K. Shmagin, R. M. Kolbas, H. C. Casey, Jr., and S. P. DenBaars, Workshop on Wide Band Gap Semiconductors: Defects and Fundamental Parameters, January 15-16, 1997, Raleigh, NC.

13. "Stimulated Emission and Gain Measurements from InGaN/GaN Heterostructures", I. K. Shmagin, J. F. Muth, R. M. Kolbas, S.

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14. "Absorption Coefficient, Exciton Binding Energy and Band Gap of GaN", J. F. Muth, I. K. Shmagin, R. M. Kolbas, H. C. Casey, Jr., S. P. DenBaars, Army Research Office Workshop on Wide Band Gap Semiconductors: Defects and Fundamental Parameters, Research Triangle Park, NC, January 15-16 1997.

15. "MOCVD Growth of Group-III Nitrides for High Quality Photonic and Electronic Devices", S. P. DenBaars, P. Kozodoy, S. Keller, Y. F. Wu, A. Ambare, M. Mack, M. Minsky, E. Hu, J. S. Speck, L. A. Coldren, U. K. Mishra, I. K. Shmagin, J. F. Muth, and R. M. Kolbas, Invited Paper presented at the Army Research Office Workshop on Wide Band Gap Semiconductors: Defects and Fundamental Parameters, Research Triangle Park, NC, January 15-16 1997.

16. "Optical Properties of High Quality Bulk GaN Single Crystals," I. K. Shmagin, J. F. Muth, R. M. Kolbas, C. M. Balkas, Z. Sitar, and R. F. Davis, accepted at the 39th Electronic Materials Conference, June 1997.

17. "Absorption Coefficient, Excitonic Structure and Band Gap of Gallium Nitride at Room Temperature Using Optical Transmission Measurements," J. F. Muth, I. K. Shmagin, R. M. Kolbas, H. C. Casey, Jr., P. Fini, S. Keller, S. P. DenBaars, accepted at the 39th Electronic Materials Conference, June 1997.

18. "Optical and Structural Characterization of InGaN Quantum-Well Heterostructures Grown by MOCVD," P. A. Grudowski, C. J. Eiting, J. Park, B. S. Shelton, D. J. H. Lambert, R. D. Dupuis, I. K. Shmagin, J. F. Muth and R. M. Kolbas, submitted to the ISCS-24.

19. "Optical Properties of InGaN Double Heterostructures and Quantum Wells Grown by Metal Organic Chemical Vapor Deposition," R. D. Dupuis, P. A. Grudowski, C. J. Eiting, J. Park, B. S. Shelton, D. J. H. Lambert, I. K. Shmagin and R. M. Kolbas, submitted to 1997 IEEE/LEOS Summer Topical Meeting.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:
Frederick Reed (Ph.D. 1997)
Dahua Zhang (Ph.D. 1993)
Irina Shmagin (Ph.D. expected Fall '97)
John Muth
Dr. Robert Kolbas (PI)

9. REPORT OF INVENTIONS (BY TITLE ONLY):
"Bias Induced Color-tuned Semiconductor Light Emitter", R. M. Kolbas, D. Zhang, U. S. patent (disclosure, July 9, 1992, NCSU file # 92-77).

BRIEF OUTLINE OF RESEARCH FINDINGS

The overall objective of this experimental program is to control the light emission properties and energy transfer mechanisms in nanoscale semiconductor structures in order to realize new or improved photonic devices. For nanostructures that are defined by buried heterojunction interfaces the focus is to define the regimes in which scattering and carrier collection dominate the performance of quantum well and superlattice devices. For nanostructures with exposed surfaces the focus is to understand the fundamental light emission mechanisms. The proposed research impacts device development and system architectures by demonstrating light emitters for wavelength division multiplexing, three dimensional IOEC structures, broadly tunable lasers, and low loss waveguides. Most recently the impact of these phenomena have been studied in the wide bandgap AlGaN material system. We have demonstrated stimulated emission in GaN, InGaN thin films and quantum well heterostructures. We have also done absorption measurements and observed multiple excitons.

Major advances resulting from this program include:

- The first demonstration of a three terminal semiconductor light emitter where the optical output intensity is controlled by the voltage applied to one of the terminals and the color is controlled by the voltage applied to the other terminal. (Bias Induced Color-Tuned Emitter, BICE)
- Demonstration of optical memory effects in InGaN that has potential applications for optical memory storage and optical signal processing.